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ABSTRACT

We have measured the nucleon-number (A) dependence of hadron pair production in 400 GeV/c proton-nucleus collisions, using Pb and Be targets. Charged hadron pairs were observed near $Y_{CM} = -0.4$ with $\Delta\phi \cong 180^{\circ}$. The A-dependence exponent rises from 1.1 to 1.2 in the range $2.0 \leq |p_{\perp 1}| + |p_{\perp 2}| \leq 4.5$ GeV/c. The dihadron $p_{\perp}$ correlation function is significantly smaller for Pb than for Be.

Several unexpected results have recently raised interest in hadron production on heavy nuclei. The multiplicity of hadron-nucleus collisions grows with nuclear size much less rapidly than a simple cascade model would predict.[1] On the other hand, the inclusive production of high-$p_\perp$ particles rises as A^α with α significantly greater than one.[2,3,4] Theoretical models which attempt to describe this behavior include multiple scattering, nucleon clusters, and decay of high-mass states.[5] We report here the results of an experiment on the A-dependence of dihadron production.[6] Only charged particles were detected, and for the purposes of this paper no distinction is made between π, K, and p. The quantum-number correlations observed in lead and beryllium will be reported elsewhere.[7]

This experiment was performed at the Fermi National Accelerator Laboratory in a 400 GeV/c proton beam, with a typical intensity of 4×10^7 sec^{-1}. Other results and a detailed description of the apparatus have been published previously.[8] The apparatus consisted of two identical magnetic spectrometers placed at 100 mr on opposite sides of the beam. In the proton-nucleon center of mass system, each spectrometer was centered at $\theta = 110^\circ$ and subtended about $\pm\ 10^\circ$ in polar angle, and $\pm\ 17^\circ$ in azimuth. The trigger required each hadron to have $p_\perp \geq 1$ GeV/c.

Measurements of the A-dependence were made with a target of nine 1.3 mm lead segments followed by three 6.1 mm beryllium segments, all 3.8 mm wide. Data were taken on both nuclei simultaneously with targets of equal width in order to eliminate uncertainties arising from beam normalization or changes in experimental conditions. The good spatial resolution of the spectrometer drift chambers allowed unambiguous identification of the target element, as shown in Figure 1. The acceptance of the spectrometer was uniform over the length of the target. The data were corrected for beam attenuation in the target.[9] To check our technique of A-dependence measurement, we calculated cross sections for upstream and downstream portions of another target of identical CH_2 segments; the values were equal to within 1%. Because of the relatively low beam rate and the unambiguous target element identification, contamination of pair production data by two independent collisions was less than 10%.

Two distinct approaches were taken in the analysis of our results. The first was simply to measure the A-dependence of the dihadron cross section; the second was to extract kinematic correlation functions from the cross sections and observe their dependence on nuclear size. In order to calculate the correlations, and also as a check of our experimental technique, we measured the A-dependence of inclusive single-hadron production. To compare with previous experiments, we have assumed that nucleon-number dependence is of the form A^{α} and that the cross sections do not vary significantly with rapidity across the narrow acceptance of the apparatus ($\Delta y = 0.25$ at $y_{CM} = -0.4$). The results are plotted in Figure 2 and are in good agreement with previous experiments.[2-4] Over the $p_{\perp}$ range from 1.0 GeV/c to 4.6 GeV/c, the exponent for single-particle production α_1 rises smoothly from 0.95 to 1.15.

The exponent α_2 for the A-dependence of dihadron production is determined similarly by taking the ratio of yields from beryllium and lead. We have measured α_2 as a function of the transverse momentum of each particle. We parametrize our results as a function of the sum, $p_s \equiv |p_{\perp 1}| + |p_{\perp 2}|$, and the difference, $p_d \equiv ||p_{\perp 1}| - |p_{\perp 2}||$, of the transverse momenta of the two detected particles. It should be noted that p_s is approximately equal to the effective mass of the dihadron pair, and p_d approximately equals the total $p_{\perp}$ of the pair. This choice of variables was selected because the ratio of lead and beryllium yields is essentially independent of p_d. Figure 3 exhibits α_2 as a function of p_s for neutral (+-) pairs and for all pairs. In the p_s range from 2.2 to 4.6 GeV/c, α_2 rises from 1.10 ± 0.01 to 1.19 ± 0.03. (Also plotted in Fig. 3 are the values of α_2 obtained in another experiment.[10]) A comparison of the single and two-particle data (Figs. 2 and 3) shows that α_1 and α_2 are approximately equal when the single-particle transverse momentum ($p_\perp$) and the two-particle sum of transverse momenta (p_s) have equal values.

We now turn to the A-dependence of the two-hadron correlation function R defined by:

$$R(p_1,p_2) \equiv \sigma_{in} \frac{E_1E_2 \; d^6\sigma/dp_1^3 \; dp_2^3}{(E_1d^3\sigma/dp_1^3)(E_2d^3\sigma/dp_2^3)}$$

where σ_{in} is the total inelastic cross section. R is the ratio per inelastic event of the probability of a particular two-particle state, to the product of uncorrelated probabilities of the corresponding single-particle states. R is unity if two-particle production is completely uncorrelated; it is greater (or less) than one if pair production is positively (or negatively) correlated. In Figure 4, R is plotted for both lead and beryllium targets as a function of p_d for several ranges of p_s. This figure demonstrates the reason for our choice of kinematic variables. R shows little dependence on p_d, but varies strongly with changes in p_s. Figure 5A shows R as a function of p_s for symmetrically produced pairs (p_d < 0.1 GeV/c). R is greater than one throughout our range of acceptance, and increases rapidly with transverse momentum. This rise has been observed elsewhere in p-p[11] and p-nucleus[12] interactions. Our data show that pairs produced in lead are less correlated than those in beryllium. Figure 5B makes a direct comparison by displaying the ratio R_{Pb}/R_{Be} as a function of p_s. As p_s increases, the correlation in lead decreases relative to the correlation in beryllium.

In summary, the A-dependence exponent for pair production with $2 \leq |p_{\perp 1}| + |p_{\perp 2}| \leq 4.5$ GeV/c, is larger than unity and rises with transverse momentum in a fashion similar to that for single particle production. The production of hadron pairs near $y_{CM} = -0.4$ is positively correlated, and the correlation is a steeply increasing function of the sum of transverse momenta. A comparison of light and heavy nuclei shows that the correlation is lower, and a less steep function of transverse momentum, for heavy nuclei.

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REFERENCES

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[1]For a review of these results see K. Zalewski in proceedings of the International Conference on High Energy Physics edited by J. R. Smith (London, 1974), p. I-93.

[2]J. W. Cronin et al., Phys. Rev. D 11, 3105 (1975).

[3]L. Kluberg et al., Phys. Rev. Lett. 38, 670 (1977).

[4]R. L. McCarthy et al., Phys. Rev. Lett. 40, 213 (1978).

[5]For a review of some of the models see H. J. Frisch, Particles and Fields, 1976, edited by H. Gordon and R. F. Peierls (National Technical Information Service, Springfield, Virginia, 1977), p. F-59.

[6]Further details may be found in D. A. Finley, PhD. Thesis, Purdue University, 1978 (unpublished).

[7]Two-Particle Quantum Number Correlations in 400 GeV/c Proton-Nucleus Collisions, D. A. Finley et al., submitted to Phys. Rev. Lett.

[8]D. Bintinger et al., Phys. Rev. Lett. 37, 732 (1976); R. Thun et al., Nucl. Instr. Meth. 138, 437 (1976); C. W. Akerlof et al., Phys. Rev. Lett. 39, 861 (1977); W. R. Ditzler et al., Phys. Lett. 71B, 451 (1977).

[9]Total inelastic cross section values of 216 mb for Be and

1930 mb for Pb are from S. P. Denisov et al., Nucl. Phys. B61, 62 (1973). These measurements were obtained using hadron beams with incident momenta covering the range from 7 to 60 GeV/c and targets with nucleon number from 7 to 238.

[10] Our results and those for Ref. 4 do not appear to be entirely consistent, although the lack of overlap of the data as a function of p_s makes it difficult to make direct comparisons. We note that the two experiments cover slightly different angular ranges and employ somewhat different methods.

[11] F. W. Busser et al., Phys. Lett. 51B, 311 (1974).

[12] R. J. Fisk, Ph.D. Thesis, State University of New York at Stony Brook, 1978 (unpublished).

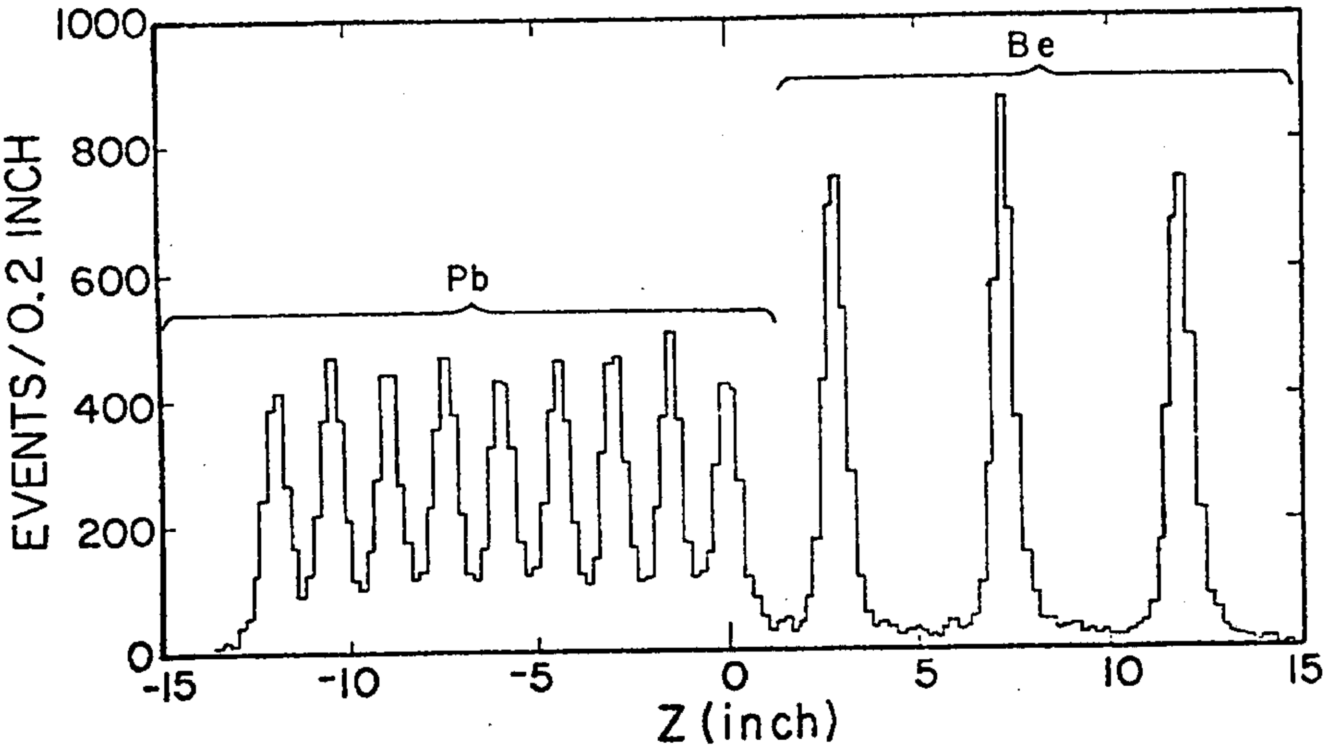

Fig. 1. Typical distribution of reconstructed target vertices along the beam line.

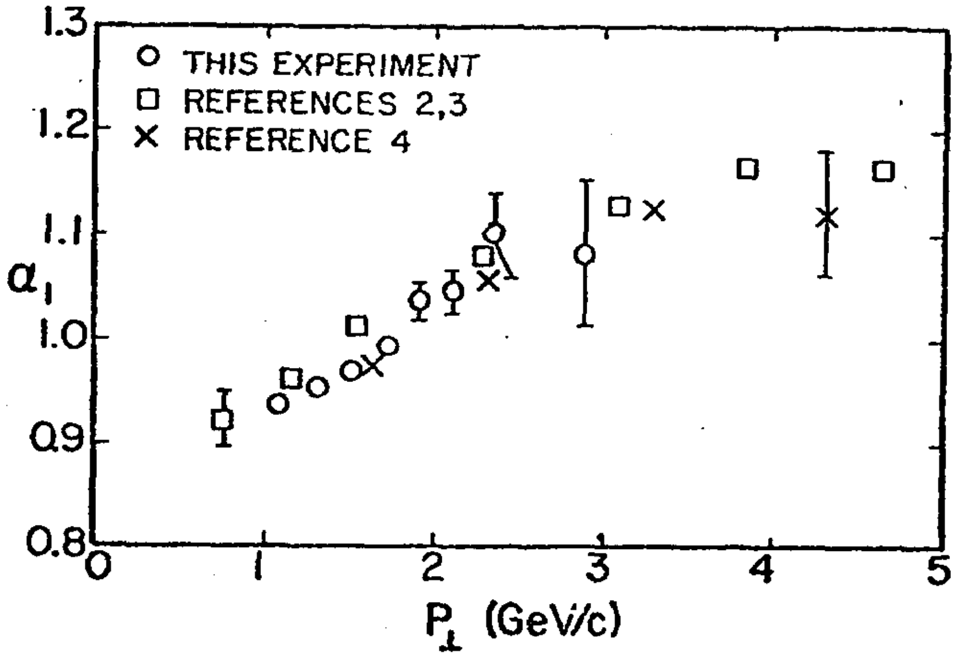

Fig. 2. Nucleon-number (A) dependence as a function of $p_\perp$ for single-hadron production. α_1 is the A-dependence exponent.

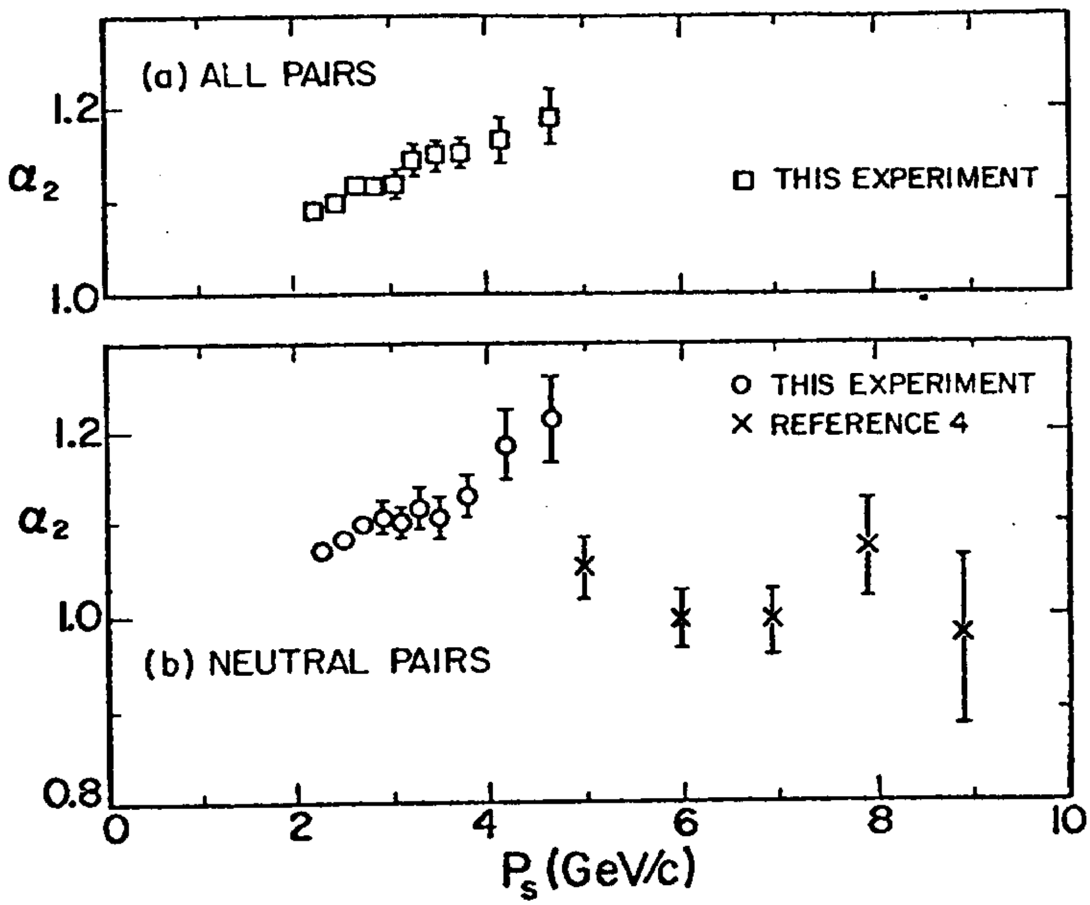

Fig. 3. The A-dependence exponent α_2 for dihadron production as a function of p_s integrated over p_d. (a) all charge combinations. (b) neutral combinations (+-, -+). The data of Ref. 4 exclude their systematic error of ±0.05 in the values of α_2. The systematic error in the values of α_2 from this experiment is estimated to be less than 0.02.

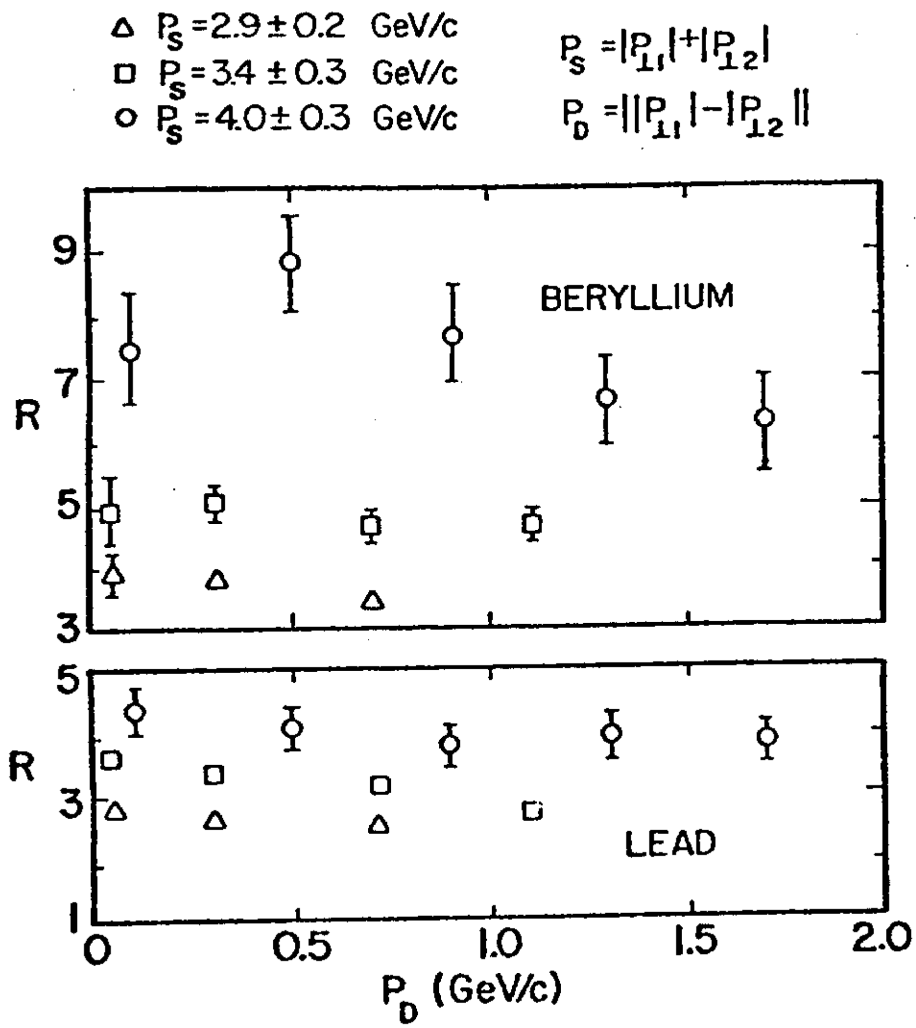

Fig. 4. The two particle transverse-momentum correlation function R as a function of p_d for various ranges of p_s.

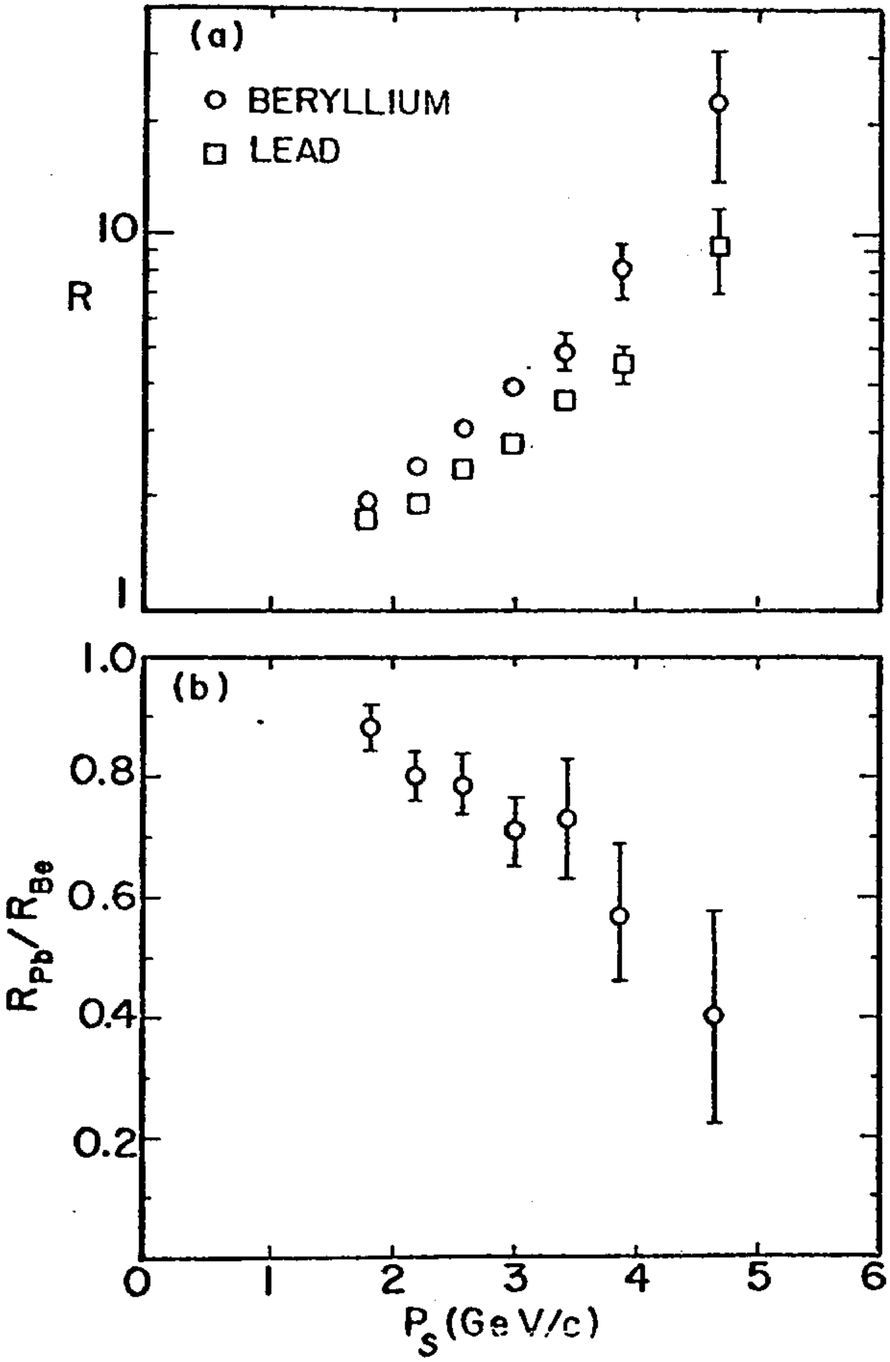

Fig. 5. (a) The two-particle transverse-momentum correlation function R as a function of $p_s = |p_{\perp 1}| + |p_{\perp 2}|$ for symmetrically produced pairs ($p_d = ||p_{\perp 1}| - |p_{\perp 2}|| \leq 0.1$ GeV/c). (b) The ratio of R for lead to R for beryllium.